PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Application of:

Haitao WU et al.

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Filed: November 17, 2003 Attorney Dkt. No.: 60282.00114

For: METHOD FOR ENHANCING FAIRNESS AND PERFORMANCE IN A MULTIHOP AD HOC NETWORK AND CORRESPONDING SYSTEM

CLAIM FOR PRIORITY UNDER 35 USC § 119

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

November 17, 2003

Sir:

The benefit of the filing dates of the following prior foreign application filed in the following foreign country is hereby requested for the above-identified patent application and the priority provided in 35 U.S.C. §119 is hereby claimed:

European Patent Application No. -3-12-47.1 filed on 28 May 2003 in Europe

In support of this claim, certified copy of said original foreign application is filed herewith.

It is requested that the file of this application be marked to indicate that the requirements of 35 U.S.C. §119 have been fulfilled and that the Patent and Trademark Office kindly acknowledge receipt of this document.

Please charge any fee deficiency or credit any overpayment with respect to this paper to Counsel's Deposit Account No. 50-2222.

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Enclosure: Priority Document (1)

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The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

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Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Method for enhancing fairness and performance in a multihop ad hoc network and corresponding system

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METHOD FOR ENHANCING FAIRNESS AND PERFORMANCE IN A MULTIHOP AD HOC NETWORK AND CORRESPONDING SYSTEM

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METHOD FOR ENHANCING FAIRNESS AND PERFORMANCE IN A MULTIHOP AD HOC NETWORK AND CORRESPONDING SYSTEM

Field of the Invention

The present invention relates to a method for enhancing the fairness and performance in a multihop ad hoc network as well as to a corresponding system therefor, and to network nodes of the system executing steps of the method.

Related Background Art

A wireless ad hoc network is a network where nodes can not communicate with each other directly as in Wireless Local Area Networks (WLAN) and may use multihop wireless links. Each node in an ad hoc network not only sends packets from itself, but also forwards packets for other nodes, thus acting as a router. Generally, an ad hoc network is self-organized and consists of nodes that support an ad hoc routing protocol, such as Dynamic Source Routing (DSR), Dynamic Sequence Distance Vector (DSDV), etc.

Contrary to an ad hoc network, Wireless Local Area Networks are developed to provide high bandwidth access for users in a limited geographical area, where nodes can communicate with each other directly. The IEEE Project 802 recommends an international standard 802.11 for Wireless Local Area Networks (see "IEEE standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications", ISO/IEC 8802-11:1999(E), Aug. 1999; and B. P. Crow, J. G. Kim: "IEEE 802.11 Wireless Local Area Networks", IEEE Communications magazine, Sept. 1997). With the Distributed Coordination

Function (DCF) according to the 802.11 standard, a four-way handshaking mechanism, which uses request-to-send/clear-to-send (RTS/CTS) technique to reserve the channel before data transmission, is proposed to solve the problem of hidden terminals. Although the collision probability for hidden terminals is thus reduced, it does not solve the problem completely.

Moreover, since the Distributed Coordination Function (DCF) is designed to work in the Wireless Local Area Network (WLAN) situation with hidden terminals, it does not work well in multihop ad hoc networks. The Distributed Coordination Function is based on Carrier Sense Multiple Access with Collision Avoidance(CSMA/CA). That is, the sender will sense whether the channel is busy before a transmission is initiated. Only when the channel is idle, the sender will transmit the packet, otherwise it will backoff a random time, which is determined by the contention window (CW) value. This mechanism works well in the Wireless Local Area Network (WLAN) scenario. However, in a multihop ad hoc network, packet collisions may occur at the receiver. Therefore, sensing the channel at the transmitter before any attempt to access the channel can not eliminate such collisions. Hence, in multihop scenario, the sender does not know the situation of the receiver and risks for collisions at the receiver.

The hidden terminal problem can be reduced by two ways: Firstly, using a slotted based synchronization mechanism with proper collision avoidance, and secondly, using another channel (see Z. J. Hass, J. Deng: "Dual Busy Tone Multiple Access (DBTMA) - A Multiple Access Control Scheme for Ad Hoc Networks", IEEE Trans. On Comm. V50, N6, June 2002, pp.975-985) to acknowledge the data packet

and prevent a possible access attempt in the receiver range, and the sender must make sure that the acknowledgment channel is idle before transmission.

However, an ad hoc network is supposed to be self-organized and currently there is no standard to synchronize all the packet transmitting times. Meanwhile, the hardware implementation cost of a two or more channel protocol is unknown, although most of them use only narrow-bandwidth, out-of-band busy tone. Therefore, a distributed Medium Access Control (MAC) protocol for one channel without specific synchronization slot mechanism is preferred. However, it is a challenging work to design such a distributed single channel Medium Access Control (MAC) protocol for a multihop network.

On the other hand, there is no scheme in the Distributed Coordination Function (DCF) to deal with the problem of exposed terminals. According to the Distributed Coordination Function (DCF), the Medium Access Control (MAC) layer ACK is used to improve the performance of the Medium Access Control (MAC) protocol in transmission errors. Therefore, the sender becomes the receiver of the Medium Access Control (MAC) acknowledgment (ACK) after it has transmitted the data packet. With a single channel, the exposed terminal problem is difficult to solve.

From the viewpoint of customers, the performance of the transport layer is the most important, no matter it runs over a Local Area Network (LAN), a Wireless Local Area Network (WLAN), or a mobile ad hoc network (MANET). The Transport Control Protocol (TCP) is the most widely used reliable transport layer protocol and is expected to work well in ad hoc networks (see e.g. K. Chandran, S. Raghunathan, et al.: "A Feedback-Based Scheme for

Improving TCP Performance in Ad Hoc Wireless Networks", IEEE Personal Comm., Feb. 2001, pp.34-39; F. Wang, Y. Zhang: "Improving TCP Performance over Mobile Ad-Hoc Networks with Out-of-Order Detection and Response", MOBIHOC'02, June 2002; C. Barakat, E. Altman, W. Dabbous: "On TCP Performance in a Heterogeneous Network: A Survey", IEEE Commun. Mag., Jan. 2000; and S. Xu, T. Saadawi: "Does the IEEE 802.11 MAC Protocol Work Well in Multihop Wireless Ad hoc Network", IEEE Commun. Mag., June 2001). How to improve the TCP performance in multihop ad hoc networks (MANET) with frequent link failures and route changes due to node mobility is the focus of recent work. Most of them require a feedback from the network layer or lower layer to change the status of TCP. According to K. Chandran, S. Raghunathan, et al.: "A Feedback-Based Scheme for Improving TCP Performance in Ad Hoc Wireless Networks", IEEE Personal Comm., Feb. 2001, pp.34-39, TCP is adapted to frequent route changes by detecting and responding an out-of-order packet delivery at the TCP layer. However, the recent study of S. Xu, T. Saadawi: "Does the IEEE 802.11 MAC Protocol Work Well in Multihop Wireless Ad hoc Network", IEEE Commun. Mag., June 2001, shows that the TCP over 802.11 DCF works poorly even if there is no mobile node. The problem lies in the Medium Access Control (MAC) protocol 802.11 DCF, where the hidden terminal problem still exists in a multihop ad hoc network, and where the binary exponential backoff (BEB) scheme of the Distributed Coordintaion Function (DCF) always favors the latest successful node.

The Medium Access Control (MAC) protocol with which stations can share a common broadcast channel is however essential in a Wireless Local Area (WLAN) or an ad hoc network. Thus, in order to address the above problems,

the following proposals have been made during the past years.

The fairness problem was first pointed out by V. Bharghavan, A. Demers, S. Shenker, L. Zhang: "MACAW: A Media Access Protocol for Wireless WLAN's", ACM SIGCOMM, 1994, pp.212-225. That is, based on a Request-to-Send/Clear-to-Send (RTS/CTS) exchange to reserve the channel before the data transmission for addressing the hidden terminals problem in single channel networks, a new protocol named MACAW using an RTS-CTS-DS-DATA-ACK message exchange and including multiple increase and linear decrease backoff strategies, has been proposed therein. The data sending (DS) packet was added to notify all nodes in the sender's range of its following use of the shared channel. Although the RTS/CTS exchange can not eliminate the hidden terminal problem, it can alleviate it to some extend. Therefore, the IEEE 802.11 committee proposed the "IEEE standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications", ISO/IEC 8802-11:1999(E), Aug. 1999, which includes a RTS/CTS exchange as an optional access method. However, MACAW uses packet sensing (PS), while the 802.11 DCF is based on CSMA/CA.

Further, it has been proposed by C. L. Fullmer, J. J. Garcia-Lura-Aceves: "Floor Acquisition Multiple Access (FAMA) for Packet-Radio Networks", ACM SIGCOMM 1995, that a station that has data to send must acquire control of the channel before sending, and that it ensures that no data packets collide with any other packets. It was also shown that carrier sensing is necessary in FAMA protocols to eliminate the hidden terminal problem efficiently in single-channel networks (see C. L. Fullmer, J. J. Garcia-Lura-Aceves: "Solutions to Hidden Terminal Problems in

Wireless Networks", ACM SIGCOMM 1997). However, the absence of data packet collisions does not mean fairness, in fact, all these protocols favor the station whose corresponding receiver has no collision.

A contention resolution algorithm that combines persistence and backoff has been proposed by T. Czugur, M. Naghshineh, P. Kermani, J. A. Copeland: "Fair Media Access for Wireless LANs", IEEE Globecom'99, pp.570-579, 1999, with two variants, connection-based and time-based. It also uses a backoff strategy and a copying scheme similar to MACAW. However, the results have shown that none of the algorithm always provides the best fair access in every scenario. Besides, there is no formal fairness objective in this scheme.

Still further, a measurement-based algorithm has been proposed by Z. Fang, B. Bensaou, Y. Wang: "Performance Evaluation of a Fair Backoff Algorithm for IEEE 802.11 DFWMAC", MOBIHOC'02, June 2002, to achieve fairness in ad hoc networks by replacing the binary exponential backoff (BEB) in the Distributed Control Function (DCF) with another backoff scheme where the contention windows are adjusted according to what the stations hears. Since it adjusts the contention window (CW) directly, the traffic load fluctuates greatly, especially in short time scale. Although it achieves somewhat fairness, the performance degrades when the density of traffic and stations increases.

A distributed Max-Min fairness framework for wireless ad hoc network has been proposed by X. L. Huang, B. Bensaou,: "On Max-Min Fairness and Scheduling in Wireless Ad-Hoc Networks: Analytical Framework and Implementation", MOBIHOC'01, Long Beach, CA, 2001. The

. An full shared assignment is achieved in a distributed way, where nodes obtain contention tree information from all their neighbor's neighbors. The backoff window is adjusted according to a fairness reference, similar to the way described by Z. Fang, B. Bensaou, Y. Wang: "Performance Evaluation of a Fair Backoff Algorithm for IEEE 802.11 DFWMAC", MOBIHOC'02, June 2002. However, without synchronization information, stations can not compete efficiently in a distributed way, thus, the whole performance may degrade.

Furthermore, T. Nandagopal, T. Kim, X. Gao, V. Bharghavan: "Achieving MAC Layer Fairness in Wireless Packet Networks", ACM Mobicom 2000, proposed a general analytical framework that captures the unique characteristics of shared wireless channels and allows the modeling of a large class of system-wide fairness models via the specification of per-flow utility functions. By combining persistence and backoff, a slotted local mechanism for proportional fair contention resolution is presented. However, how to implement such framework in a distributed way without synchronization is unknown.

A distributed priority scheduling technique that piggybacks the priority tag of a node's head-of-line packet onto the handshake(RTS/CTS) frames and data frame has been proposed by V. Kanodia, C. Li, A. Sabharwal, B. Sadeghi, E. Knightly: "Distributed Multi-Hop Scheduling and Medium Access with Delay and Throughput Constraints", ACM SIGMOBILE, 2001, pp.200-209. Each node locally constructs a scheduling table based on overhead information, and incorporates its estimate of its relative priority into the Medium Access Control (MAC). The scheme is further enhanced by receiver participation

and stale entry elimination as described by V. Kanodia, C. Li, A. Sabharwal, B. Sadeghi, E. Knightly: "Ordered Packet Scheduling in Wireless Ad Hoc Networks: Mechanisms and Performance Analysis", MOBIHOC'02, June 2002.

Accordingly, the above emphasizes why the performance of TCP over ad hoc network has been the research focus recently. Specifically, since a node in MANET is likely in motion, the communication links between nodes will likely be broken frequently, which leads to mass packet losses and degrades TCP performance greatly. As described above, a feedback-based scheme for improving the TCP performance in ad hoc wireless network has been proposed by K. Chandran, S. Raghunathan, et al.: "A Feedback-Based Scheme for Improving TCP Performance in Ad Hoc Wireless Networks", IEEE Personal Comm., Feb. 2001, pp.34-39. The TCP source enters a snooze state after it receives a router failure notification packet and freezes its sending window until it receives the route reestablishment notification packet.

Another proposal according to F. Wang, Y. Zhang: "Improving TCP Performance over Mobile Ad-Hoc Networks with Out-of-Order Detection and Response", MOBIHOC'02, June 2002 is to make TCP adapt to frequent route changes by detecting and responding out-of-order packet delivery at TCP layer. In fact, most of the work deals with the link failure and route change problems caused by node mobility.

However, recently studies according to S. Xu, T. Saadawi, "Does the IEEE 802.11 MAC Protocol Work Well in Multihop Wireless Ad hoc Network", IEEE Commun. Mag., June 2001, shows that the performance and fairness of the Medium Control Access (MAC) protocol in ad hoc network

greatly. A conclusion of this document is that the current WLAN IEEE 802.11 DCF does not function well in a multihop ad hoc network.

However, as is described in the following with respect to Figs. 1(a) and 1(b), all the Medium Access Control (MAC) protocols mentioned above have the same problem.

Namely, the fairness problem was first pointed out by V. Bharghavan, A. Demers, S. Shenker, L. Zhang: "MACAW: A Media Access Protocol for Wireless WLAN's", ACM SIGCOMM, 1994. pp.212-225. This problem occurs mainly because of hidden terminal problems as well as the binary exponential backoff (BEB) scheme used in the Medium Access Control (MAC) protocol.

The scenario will be described with respect to Fig. 1(a) and (b). There are two flows in the illustrated configuration, flow 1 is from node N1 to node N2, and flow 2 is from node N4 to node N3 in case (a) and opposite in case (b). The carrier sensing range (and interfering range) is supposed to be the same as the communication range according to V. Bharghavan, A. Demers, S. Shenker, L. Zhang: "MACAW: A Media Access Protocol for Wireless WLAN's", ACM SIGCOMM, 1994. pp.212-225, which is different from the supposition according to S. Xu, T. Saadawi, "Does the IEEE 802.11 MAC Protocol Work Well in Multihop Wireless Ad hoc Network", IEEE Commun. Mag., June 2001. A larger sensing range and interfering ranges will degrade the network performance severely. Therefore, a term range is used to refer both the communication range and sensing/interfering range of a node. The range of a node transmitting data is covered by a solid line, while the range of a node receiving data

is covered by a dashed line. Since the Request-to-Send/Clear-to-Send (RTS/CTS) handshaking mechanism alleviates the hidden terminal problem, it is assumed that Request-to-Send/Clear-to-Send (RTS/CTS) is always used, except for a broadcast frame. In addition, it is supposed that both flows have enough traffic, i.e. the transmitting node always has data to send.

The configuration according to Fig. 1(a) is symmetric, i.e. the competition between flow 1 and flow 2 is fair in large time scale. However, there exists an extreme unfairness in the time scale of seconds. It shall be supposed that flow 1 reserves the channel successfully by Request-to-Send/Clear-to-Send (RTS/CTS), then node N3 can not reply the RTS from node N4 because it is under defer. Node N4 will retransmit the RTS frame again and again until it reaches the retransmission limit, which is seven for 802.11 DCF. Since flow 1 finishes the packet exchange successfully, it will reduce its contention window (CW) to CW_{min}, which is 31 according to 802.11 DCF. However, the contention window (CW) of node N2 will double every time after a failed access until it reaches the retransmission limit and the contention window (CW) will be reset to CW_{min} again. The only chance that flow 2 can successfully initiate a transfer is when its RTS happens to arrive during those very short gaps in between a completed data transmission and the next RTS from node N1. The opposite scenario may happen where flow 2 seizes the channel and flow 1 can not get the channel.

The following observations can be obtained in simulations: If the User Datagram Protocol (UDP) is used as the transport layer protocol, i.e. there is no congestion control and flow control at the transport layer, then flow 1 grabs the channel from one to ten

(... 2 can not send any packet in this period), and after that, flow 2 grabs the channel and flow 1 can not send any packet. If the Transport Control Protocol TCP is used as the transport layer protocol, then the results are different. When one flow grabs the channel, the other flow can not get the channel, and the TCP agent of that node will time-out and retransmit at the transport layer, causing it to be unlikely to grab the channel again. However, which flow will grab the channel and starve the other flow is somewhat random.

Similar to the issues as analyzed by V. Bharghavan, A. Demers, S. Shenker, L. Zhang: "MACAW: A Media Access Protocol for Wireless WLAN's", ACM SIGCOMM, 1994. pp.212-225, the key problem is the lack of synchronizing information. When one flow (suppose flow 1) grabs the channel, the other flow access will be successful only in the short period after the transmission of flow 1 and its next access attempt. However, node N4 has no way of knowing whether node N1 is transmitting. According to V. Bharghavan, A. Demers, S. Shenker, L. Zhang: "MACAW: A Media Access Protocol for Wireless WLAN's", ACM SIGCOMM, 1994. pp.212-225, the problem is solved by having node N3 not contending on behalf of node N4. Node N3 uses a "Request for RTS" (RRTS) to trigger the RTS from node N4. Although RRTS packet works well in the configuration according to Fig. 1(a), it can not solve the contention problem according to Fig. 1(b).

By referring to the configuration according to Fig. 1(b), node N2 (the receiver of flow 1) is in the range of node N3 (the sender of flow 2). The simulation results show that flow 2 grabs the channel, while flow 1 is completely denied access most of the time, especially when TCP is used at the transport layer. The key problem is not only

the lack of synchronizing information. Node N1 is trying to contend with node N3 during a very short contention period, but node N1 has no way of knowing when this period starts or finishes. The RRTS can not solve the problem in this scenario, because most of the time when node N1 initiates a data transfer by sending a RTS, node N2 can not hear it due to node N3's transmission. The situation preserves even when nodes N1 and N3 are synchronized well, i.e., node N1 and N3 start competing to access the channel at the same time using the same contention window (CW) counter. The only chance that node N1 could access the channel is that node N3 tries to access the channel after the RTS/CTS exchange of flow 1 is finished, then node N3 will hear the CTS from node N2 and stop trying access the channel.

The same problem occurs not only for the 802.11 DCF, but also for all the Medium Access Control (MAC) protocols mentioned above. As it can be seen from the previous example, the issue lies not only in the lacking of synchronization information, but also in the backoff scheme and in the contention window (CW) resetting scheme after a successful transfer of a stream.

Summary of the Invention

Therefore, it is an object of the present invention to overcome the shortcomings discussed above. Particularly, the present invention aims at providing a method presenting the synchronization information for competing streams and a new backoff scheme for succeeded stations.

According to the present invention, this object is solved by providing a method for enhancing the fairness and performance in a multihop ad hoc network, comprising

on synchronization information regarding a transmission between nodes of the network, wherein the information is provided to nodes in a range of two hops from the nodes participating at the transmission; setting, after successfully finishing the transmission, a waiting time for the nodes participating at the transmission, in which these nodes backoff from accessing a transmission medium.

Alternatively, the contention synchronization information can be provided by generating a black burst energy signal by each node receiving a transmission request or a transmission clearance, the black burst energy signal indicating the busy time of the transmission medium according to a mapping scheme.

As a preferred implementation the method accords to the Distributed Coordination Function as defined by the international standard 802.11 for Wireless Local Area Networks of the IEEE.

In this case, the transmission request is the Request-to-Send packet, the transmission clearance is the Clear-to-Send packet, and the waiting time is equal to the time for a Request-to-Send/Clear-to-Send-handshaking plus the total backoff time of the minimum contention window.

In a preferred embodiment of the present invention, the method comprises backing off by a node using a random value uniformly chosen between [0, CW_{min}] before accessing a channel, when a packet arrives to a Medium Access Control Layer from a higher layer; generating a black burst energy signal according to the mapping scheme, when a node receives a Request-to-Send or Clear-to-Send not

for itself, wherein the black burst energy signal is not sent if the node detects the channel is busy; receiving the black burst energy signal by a first node and attempting to access the channel by the first node for limited times before the end point of the time indicated by the black burst energy signal, wherein these attempts are not added to the retransmission times for the packet; starting a backoff timer at the end point of the time indicated by the black burst energy signal by using a random value uniformly chosen between [0, CW_{min}], while the contention window for this node is not reset, if the first node detects the channel is idle, wherein only the earliest time point is used if more than one black burst energy signal is received; and waiting for a time period after a successful transmission, before a sender node and a receiver node access the channel again, wherein the length of the time period equals to the time for a Request-to-Send/ Clear-to-Send-handshaking plus the total backoff time of the minimum contention window.

As an option the end point of the time indicated by the black burst energy signal is calculated according to

$$T_i = T_{curr} + T_{SIFS} + T_{CTS} + T_{TR} + T_{BB} + T_{DATA},$$

wherein T_{curr} is the time when the black burst energy signal is received and T_{BB} is the transmission time for the black burst energy signal.

In this case the end point of the time indicated by the black burst energy signal may coincide with the end of the DATA packet frame, if the black burst energy signal was generated due to a Request-to-Send packet, and wherein the end point of the time indicated by the black burst energy signal may be near the finish time of the

frame with a difference of turnaround time plus black burst energy signal transmission time, if the black burst energy signal was generated due to a Clear-to-Send packet.

Moreover, according to the present invention the object is solved by providing a system for enhancing the fairness and performance in a multihop ad hoc network, comprising means for providing contention synchronization information regarding a transmission between nodes of the network, and for providing the information to nodes in a range of two hops from the nodes participating at the transmission; means for setting a waiting time for the nodes participating at the transmission after a successful finish of the transmission, in which these nodes backoff from accessing a transmission medium.

The system according to the present invention can be modified in a similar manner as is outlined above with respect to the method according to the present invention. Particularly, the system according to the present invention can be adapted to perform the method according to the present invention and its modifications.

As a further preferred embodiment of the present invention, there is provided a node according to the international standard 802.11 for Wireless Local Area Networks of the IEEE, wherein the node is adapted to back off using a random value uniformly chosen between [0, CW_{min}] before accessing a channel, when a packet arrives to a Medium Access Control Layer from a higher layer; the node is adapted to generate a black burst energy signal according to the mapping scheme, when it receives a Request-to-Send or Clear-to-Send not for itself, wherein the black burst energy signal is not sent if the node

detects the channel is busy; the node is adapted to receive the black burst energy signal and attempts to access the channel for limited times before the end point of the time indicated by the black burst energy signal, wherein these attempts are not added to the retransmission times for the packet; the node is adapted to start a backoff timer at the end point of the time indicated by the black burst energy signal by using a random value uniformly chosen between [0, CW_{min}], while the contention window for this node is not reset, if the node detects the channel is idle, wherein only the earliest time point is used if more than one black burst energy signal is received; and the node is adapted to wait for a time period after a successful transmission, before the channel is accessed again, wherein the length of the time period equals to the time for a Request-to-Send/ Clear-to-Send-handshaking plus the total backoff time of the minimum contention window.

Also the node according to the present invention may be modified in a manner as outlined above and/or so as to perform the method according to the present invention.

An implementation of the method according to the present invention may be named BBDCF (Black Burst Distributed Coordination Function). According to the method of the present invention, the fairness and performance of the MAC protocol in multihop ad hoc networks is improved. In the BBDCF, the black burst (BB) energy is used to signal the data transmission time to all the nodes in two-hop range from the data sender and receiver. Therefore, all possible access attempts that may affect the current transmission are synchronized by the BB signal and will complete the channel access in a more efficient and fair way.

Thus, the fairness and performance of the MAC protocol as the currently considered main issue for transport optimization in wireless packet network is addressed. This issue roots in the design of the MAC protocol. The solution to these problems as according to the present invention benefits the performance for transport protocol in WLAN with hidden terminals, the hot spot wireless network with hidden terminals, and ad hoc network, where a connection may be relayed by multiple nodes.

According to the present invention, a solution to the fairness and performance issue in multihop ad hoc networks is presented. Since to the inventor's knowledge there is currently no other solution that is designed for a distributed network, such as a mobile ad hoc network, this is an important progress for the present field.

It is a further advantage of the present invention that the BBDCF is based on IEEE 802.11 DCF, i.e. it is a modification of the IEEE 802.11 DCF, wherein the implementation cost is low and no control or management frame will be introduced.

Brief Description of the Drawings

Further details and advantages of the present invention will become more readily apparent from the following description of the detailed description of the preferred embodiments of the present invention which is to be taken in conjunction with the appended drawings, in which:

Fig. 1 shows a two-stream configuration according to the prior art;

Fig. 2 shows a hidden competition in multihop scenario as underlying the present invention; and

Fig. 3 shows the Black Burst Distributed Coordination Function (BBDCF) access method according to the present invention with Request-to-Send/Clear-to-Send (RTS/CTS) exchange.

Detailed Description of the preferred Embodiments

In the following, a preferred embodiment of the present invention is described in detail by making reference to the drawings.

Specifically, the preferred embodiment of the present invention is an example of an implementation of an algorithm. In detail, the implementation shall be named as Black Burst Distributed Coordination Function which provides synchronization information for competing streams. Involved in such competing streams are stations which are hidden from each other, i.e., they are not in the range of each other. Hence, the competition between hidden terminals is called as hidden competition here. The hidden competition scenario can be illustrated according to Fig. 2.

When station A is trying to communicate with station B, node H acts as a hidden terminal for node A. On the other hand, node E acts as an exposed terminal. In Fig. 2, the respective range of source station A and destination station B is shown by a corresponding solid circles, while the respective two-hop range of stations A and B is shown by dashed circles. Here, the two-hop range means the stations in this range can be reached by no more than two hops. Those stations in solid circle range covered by

are supposed to be able to use a Network Allocation Vector (NAV) to perform a virtual carrier sense at the Medium Access Control (MAC) layer if the Request-to-Send/Clear-to-Send (RTS/CTS) exchange of nodes A and B is carried out successfully. However, the situation observed by nodes in two-hop range but out of the one-hop range is different.

It shall be supposed that node A is sending a data frame to node B after the Request-to-Send/Clear-to-Send (RTS/CTS) exchange. Node F will observe the carrier is clear and may try to access the channel and send an RTS frame to node E. Node E cannot receive any frame correctly, because node A is also transmitting, which is the situation underlying Fig. 1(b). However, if node F is trying to communicate with another node G, then it will not be affected by the transmission from node A to node B. Since every node in a wireless multihop ad hoc network is supposed to be self-organized and is moving, the exact physical location information is difficult to obtain. Besides, even if the node could obtain such information, it also needs to know whether a transmission occurring in two-hop range will affect the current access.

Therefore, the problem lies in the lack of information of transmission from nodes in the two-hop range. According to the present invention, the Black Burst Distributed Coordination Function (BBDCF) protocol is presented to provide information to stations in the two-hop range, which is shown in Fig. 3.

The Black Burst (BB) signal is a pure energy signal and contains no decodable information. It is supposed here that the station receiving the BB signal can sense the channel is busy and can tell how long the busy time is.

As shown in Fig. 3, the BB energy signal is transmitted when a station hears an RTS frame (stations in source range) or a CTS frame (stations in destination range) not for itself. According to the present invention, the BB energy signal has two functions:

1) It notifies that a transmission has started in two-hop range. However, at this time, even if a station has received such a BB energy signal, it can not tell whether it could access the channel. For example, even if node F has received a BB signal from node E after node A has transmitted the RTS frame, it can not tell whether it could start the access. This is because if the access is to node G, then it will succeed, and if the access is to node E, then it will fail. Therefore, after receiving the BB signal a station will have to try the access for limited times, but such attempts should not be counted as the retransmission number of the packet at the Medium Access Control (MAC) layer.

2) From the received BB energy signal, the stations can deduce the time when the transmission two hops away will be over. The reason is that the packet length is distributed densely around some discrete points, such as 40, 552 and 576 bytes. Therefore, a mapping scheme between the data packet length and BB signal length can be defined. That is, from the length of the BB energy signal, the station can predict the length of the data packet in transmission. It shall be noted that when a station receives a BB energy signal, it can not tell whether it is a BB-RTS or BB-CTS (see Fig. 3). That is, the time point indicated by the BB-RTS, which is generated from the nodes hearing RTS, and BB-CTS, which is generated from the nodes hearing CTS, is different. This difference is designed to provide fairness.

The time indicated by the BB energy signal is calculated as follows:

$$T_i = T_{curr} + T_{sifs} + T_{CTS} + T_{TR} + T_{BB} + T_{DATA},$$

where T_i is the indication time, T_{curr} is the time when the BB energy signal is received, and T_{BB} is the transmission time for the BB energy signal. Others are set according to the 802.11 standard.

Therefore, the time point indicated by BB-RTS is just the time when the DATA frame has been transmitted.

By referring back to Fig. 1(b), it is explained in detail why not the time point after the ACK frame is indicated. After flow 2 reserves the channel and transmits its DATA frame, the range of node N2 is clear. Then, from this time, node N1 could access the channel by sending its RTS frame to node N2 and will not affect or be affected by the transmission of flow 2, because the length of the RTS frame is larger than that of the CTS frame.

On the contrary, supposing that the time point after the ACK frame is used to indicate node N1 to start its competition, then node N1 will likely be affected by the next transmission attempt from node N3 as described above in the introductory portion, which is caused by the unfair competition between nodes N1 and N3.

On the other hand, the time indicated by BB-CTS is near the finish time of the ACK frame with a difference of the turnaround time plus the BB transmission time. This setting is easy to understand when considering the

situation according to Fig. 1(a). The competition of node N1 and node N4 is fair and should start from the same time point.

The BB energy signal length is much smaller than that of the RTS, CTS or DATA frame. For example, in a Dynamic Congestion Control Scheme of the physical layer, if the physical bandwidth is 2Mbps, the transmission time for RTS and CTS are 352μs and 304μs separately, while a present simulation reveals that the BB energy signal used is from 10μs to 50μs. Therefore, the difference between collisions of control packet frames or data packet frames and BB energy signals can easily be told.

In the following the method and system according to the present invention are described in detail.

When a packet arrives at the Medium Access Control (MAC) layer from a high layer, even if the channel is idle, then the node starts a backoff using a random value uniformly chosen between [0, CW_{min}] before accessing the channel.

If a station receives a RTS or CTS not for itself, then it generates a BB energy signal according to a mapping scheme defined beforehand. If the node detects the channel is busy (including by a Network Allocation Vector - NAV), then it can not send the BB energy signal. Otherwise, the BB may affect the ongoing transmission. It is noted that the Network Allocation Vector (NAV) setting by RTS or CTS should not restrict their corresponding BB energy signal, since otherwise no BB energy signal could can be sent at all.

ing a BB energy signal will attempt to access the channel for limited times before the time point indicated by the BB energy signal. These attempts will not be added to the retransmission times for the packet, which is used to determine whether the packet should be dropped.

At the time point indicated by the BB energy signal, if the node detects that the channel is idle, it should start a backoff timer using a random value uniformly chosen between [0, CW_{min}], while the contention window (CW) for this node will not be reset.

If more than one BB energy signal is received, then only the earliest time point will be used.

After a successful transmission, both the sender node and the receiver node should wait for a time period before accessing the channel again. The length of this time period equals to the time for an Request-to-Send/Clear-to-Send (RTS/CTS) handshaking plus the total backoff time of CW_{min}.

It is further noted that the waiting time in force may degrade the performance in the scenario of a Wireless Local Area Network (WLAN), where there is only one hop and has no hidden competition at all. However, the point is that a WLAN protocol that is designed for a one hop scenario works poorly in a multihop scenario, and vice versa.

The above implementation is based on the implementation of IEEE 802.11 DCF, since the preferred embodiment of the present invention relies on the RTS/CTS/DATA/ACK handshaking and the CSMA/CA of 802.11 DCF.

For the implementation, the physical wireless network card and card driver can be advantageously used.

Since the preferred embodiment of the present invention refers to the IEEE 802.11 standards, it can be regarded as a performance enhancement scheme for IEEE 802.11 standards in a multihop wireless network.

What is described above is a method for enhancing the fairness and performance in a multihop ad hoc network, comprising providing contention synchronization information regarding a transmission between nodes of the network, wherein the information is provided to nodes in a range of two hops from the nodes participating at the transmission; setting, after successfully finishing the transmission, a waiting time for the nodes participating at the transmission, in which these nodes backoff from accessing a transmission medium.

While it has been described above what is presently considered to be preferred embodiments of the present invention, it is to be understood that these are presented by way of example only and that various modifications may be made without departing from the scope of the appended claims.

Claims

1. A method for enhancing the fairness and performance in a multihop ad hoc network, comprising

providing contention synchronization information regarding a transmission between nodes of the network, wherein the information is provided to nodes in a range of two hops from the nodes participating at the transmission;

setting, after successfully finishing the transmission, a waiting time for the nodes participating at the transmission, in which these nodes backoff from accessing a transmission medium.

2. The method according to claim 1, wherein the contention synchronization information is provided by generating a black burst energy signal by each node receiving a transmission request or a transmission clearance, the black burst energy signal indicating the busy time of the transmission medium according to a mapping scheme.

3. The method according to claim 2, wherein the method accords to the Distributed Coordination Function as defined by the international standard 802.11 for Wireless Local Area Networks of the IEEE.

4. The method according to claim 3, wherein the transmission request is the Request-to-Send packet, the transmission clearance is the Clear-to-Send packet, and the waiting time is equal to the time for a Request-to-Send/ Clear-to-Send-handshaking plus the total backoff time of the minimum contention window.

5. The method according to claim 4, comprising

backing off by a node using a random value uniformly chosen between [0, CW_{min}] before accessing a channel, when a packet arrives to a Medium Access Control Layer from a higher layer;

generating a black burst energy signal according to the mapping scheme, when a node receives a Request-to-Send or Clear-to-Send not for itself, wherein the black burst energy signal is not sent if the node detects the channel is busy;

receiving the black burst energy signal by a first node and attempting to access the channel by the first node for limited times before the end point of the time indicated by the black burst energy signal, wherein these attempts are not added to the retransmission times for the packet;

starting a backoff timer at the end point of the time indicated by the black burst energy signal by using a random value uniformly chosen between [0, CW_{min}], while the contention window for this node is not reset, if the first node detects the channel is idle,

wherein only the earliest time point is used if more than one black burst energy signal is received; and

waiting for a time period after a successful transmission, before a sender node and a receiver node access the channel again, wherein the length of the time period equals to the time for a Request-to-Send/ Clear-to-Send-handshaking plus the total backoff time of the minimum contention window.

6. The method according to claim 5, wherein the end point of the time indicated by the black burst energy signal is calculated according to

$$T_i = T_{curr} + T_{SIFS} + T_{CTS} + T_{TR} + T_{BB} + T_{DATA} ,$$

wherein T_{curr} is the time when the black burst energy signal is received and T_{BB} is the transmission time for the black burst energy signal.

7. The method according to claim 5, wherein the end point of the time indicated by the black burst energy signal coincides with the end of the DATA packet frame, if the black burst energy signal was generated due to a Request-to-Send packet, and wherein the end point of the time indicated by the black burst energy signal is near the finish time of the ACK frame with a difference of turnaround time plus black burst energy signal transmission time, if the black burst energy signal was generated due to a Clear-to-Send packet.

8. A system for enhancing the fairness and performance in a multihop ad hoc network, comprising

means for providing contention synchronization information regarding a transmission between nodes of the network, and for providing the information to nodes in a range of two hops from the nodes participating at the transmission;

means for setting a waiting time for the nodes participating at the transmission after a successful finish of the transmission, in which these nodes backoff from accessing a transmission medium.

9. The system according to claim 8, comprising a node for receiving a transmission request or a transmission clearance, and for generating a black burst energy signal by each such receipt, the black burst energy signal indicating the busy time of the transmission medium according to a mapping scheme, thus providing the contention synchronization information.

10. The system according to claim 9, the system being in accordance to the international standard 802.11 for Wireless Local Area Networks of the IEEE.

11. The system according to claim 10, wherein the transmission request is the Request-to-Send packet, the transmission clearance is the Clear-to-Send packet, and the waiting time is equal to the time for a Request-to-Send/ Clear-to-Send-handshaking plus the total backoff time of the minimum contention window.

12. The system according to claim 11, comprising at least a first node, a sender node and a receiver node, wherein

the sender node is adapted to back off using a random value uniformly chosen between [0, CW_{min}] before accessing a channel, when a packet arrives to a Medium Access Control Layer from a higher layer;

the first node is adapted to generate a black burst energy signal according to the mapping scheme, when it receives a Request-to-Send or Clear-to-Send not for itself, wherein the black burst energy signal is not sent if the first node detects the channel is busy;

the first node is adapted to receive the black burst energy signal and attempt to access the channel for limited times before the end point of the time indicated by the black burst energy signal, wherein these attempts are not added to the retransmission times for the packet;

the first node is adapted to start a backoff timer at the end point of the time indicated by the black burst energy signal by using a random value uniformly chosen between [0, CW_{min}], while the contention window for this node is not reset, if the first node detects the channel is idle,

wherein only the earliest time point is used if more

than one black burst energy signal is received; and

the sender node and the receiver node are adapted to wait for a time period after a successful transmission, before the channel is accessed again, wherein the length of the time period equals to the time for a Request-to-Send/ Clear-to-Send-handshaking plus the total backoff time of the minimum contention window.

13. The system according to claim 12, wherein the end point of the time indicated by the black burst energy signal is calculated by the nodes according to

$$T_i = T_{curr} + T_{SIFS} + T_{CTS} + T_{TR} + T_{BB} + T_{DATA},$$

wherein T_{curr} is the time when the black burst energy signal is received and T_{BB} is the transmission time for the black burst energy signal.

14. The system according to claim 12, wherein the end point of the time indicated by the black burst energy signal coincides with the end of the DATA packet frame, if the black burst energy signal was generated by a node due to a Request-to-Send packet, and wherein the end point of the time indicated by the black burst energy signal is near the finish time of the ACK frame with a difference of turnaround time plus black burst energy signal transmission time, if the black burst energy signal was generated by a node due to a Clear-to-Send packet.

15. A node according to the international standard 802.11 for Wireless Local Area Networks of the IEEE, wherein

the node is adapted to back off using a random value uniformly chosen between [0, CW_{min}] before accessing a channel, when a packet arrives to a Medium Access Control

higher layer;

the node is adapted to generate a black burst energy signal according to the mapping scheme, when it receives a Request-to-Send or Clear-to-Send not for itself, wherein the black burst energy signal is not sent if the node detects the channel is busy;

the node is adapted to receive the black burst energy signal and attempts to access the channel for limited times before the end point of the time indicated by the black burst energy signal, wherein these attempts are not added to the retransmission times for the packet;

the node is adapted to start a backoff timer at the end point of the time indicated by the black burst energy signal by using a random value uniformly chosen between $[0, CW_{min}]$, while the contention window for this node is not reset, if the node detects the channel is idle,

wherein only the earliest time point is used if more than one black burst energy signal is received; and

the node is adapted to wait for a time period after a successful transmission, before the channel is accessed again, wherein the length of the time period equals to the time for a Request-to-Send/ Clear-to-Send-handshaking plus the total backoff time of the minimum contention window.

16. The node according to claim 15, wherein the end point of the time indicated by the black burst energy signal is calculated by the node according to

$$T_i = T_{curr} + T_{SIFS} + T_{CTS} + T_{TR} + T_{BB} + T_{DATA} ,$$

wherein T_{curr} is the time when the black burst energy signal is received and T_{BB} is the transmission time for the black burst energy signal.

17. The node according to claim 15, wherein the end point of the time indicated by the black burst energy signal coincides with the end of the DATA packet frame, if the black burst energy signal was generated by the node due to a Request-to-Send packet, and wherein the end point of the time indicated by the black burst energy signal is near the finish time of the ACK frame with a difference of turnaround time plus black burst energy signal transmission time, if the black burst energy signal was generated by the node due to a Clear-to-Send packet.

Abstract

A method for enhancing the fairness and performance in a multihop ad hoc network, comprising providing contention synchronization information regarding a transmission between nodes of the network, wherein the information is provided to nodes in a range of two hops from the nodes participating at the transmission; setting, after successfully finishing the transmission, a waiting time for the nodes participating at the transmission, in which these nodes backoff from accessing a transmission medium.

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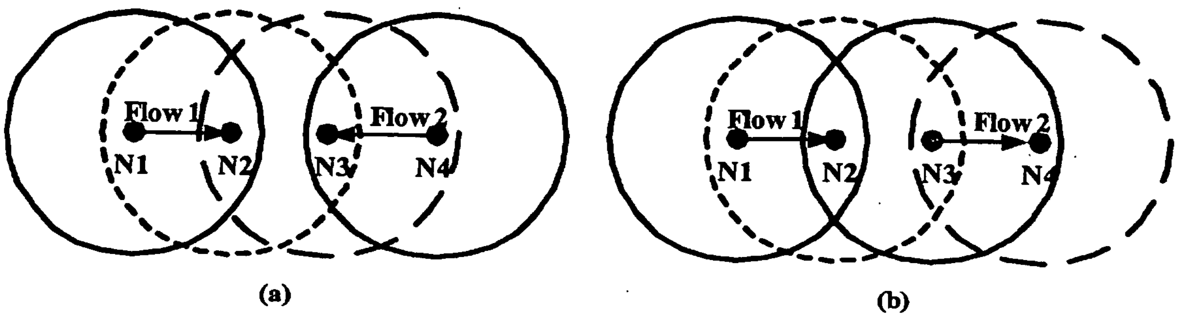

FIG. 1

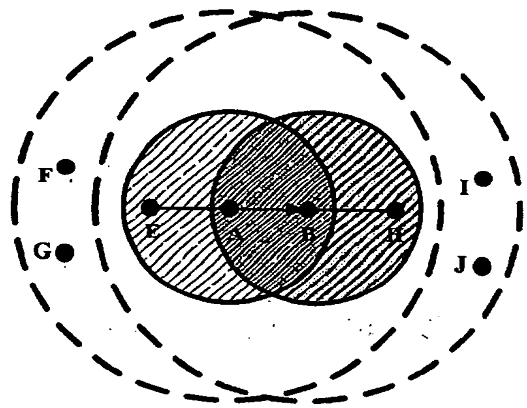

FIG. 2

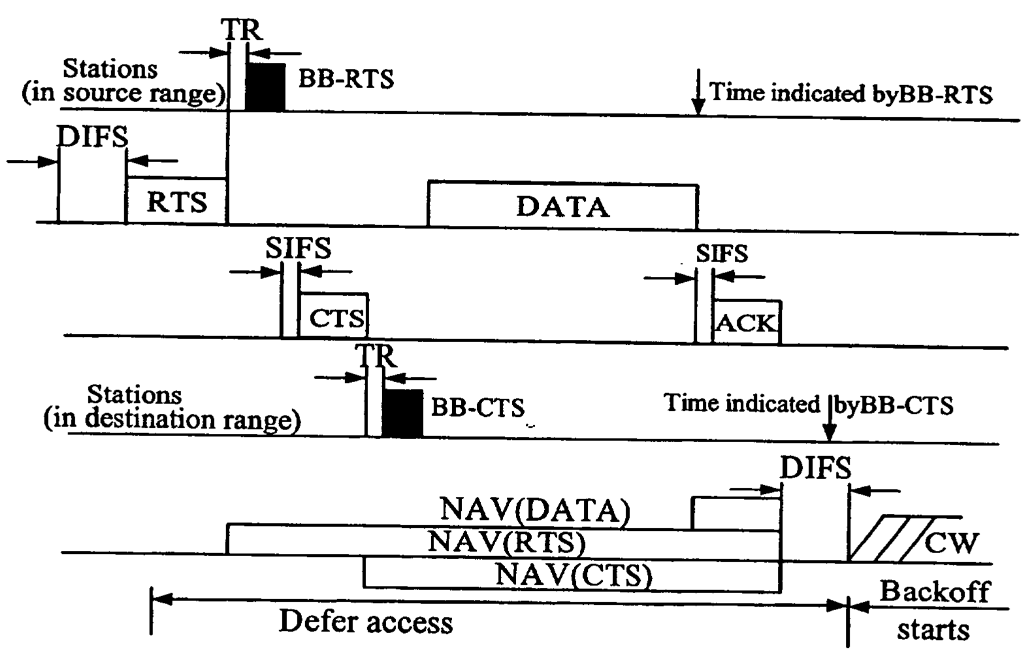

FIG. 3